ASTR3002 homework assignment 4:

Q1: Light from dust vs light from planets. (20%)

Answer the following questions with 'back-of-the-envelope calculations' – do not attempt to be more precise than ±30% – using assumptions and background facts as stated below:

(i) You are on a spaceship viewing the Solar System from a distance. Sunlight is reflected by the planets. Interplanetary dust permeates the plane of the inner Solar System and reflects sunlight as well. Which component reflects more light: the planets or the interplanetary dust?

(ii) Throughout the Galaxy, you find the mass of cool interstellar dust to be 1% of the mass in stars. Assuming a similar dust ratio when the Solar System formed, how does the initial dust mass compare with the present dust mass in the Solar System and with the mass in planets? Speculate about an explanation for these numbers.

(iii) You have parked your spaceship in the super-galactic void and look back at the Galaxy with infrared eyes. Which source dominates the thermal IR luminosity of the Galaxy: the cool dust in the interstellar medium or the billions of rocky planets warmed by their parent stars?

Assumptions and background facts:

For simplicity, we assume the Solar System is home to four identical rocky planets, each with a diameter of 10,000 km, a density of 5 g/cm^3, a surface temperature of T=450 K (these are sort of weighted averages of the warm rocky inner planets Mercury, Venus, Earth, and Mars).

The interplanetary dust currently found in the Solar System has an average grain size of 10μm and would form an asteroid of 15 km diameter if collected into a single round body with a density of 2.5 g/cm^3 (as is typical for asteroids).

We assume the entire Galaxy to be made of 100 billion Sun-like stars, each of which will be home to similar planetary systems. The interstellar dust in the Galaxy has a temperature of T=15 K, and its mass is about 1% of the mass in stars. Thermal emission from solid bodies is assumed to follow the blackbody law.

Q2: How do the Milky Way and Andromeda Galaxy compare to other galaxies? (40%)

First, we need to determine star-formation rates from near-ultraviolet (NUV) magnitudes. The NUV-band luminosity of a galaxy is roughly proportional to its star-formation rate, unless the fraction of young stars hidden behind dust varies a lot (which it does, unfortunately!).

The "AB magnitude" used for the GALEX bands is defined as ABmag = –2.5 log10(f_ν) – 48.60 with f_ν in units of erg/s/Hz/cm^2. The central wavelength of the NUV band is λ=235 nm. A calibration for star-formation rates derived from NUV luminosity is $SFR_{NUV} = 3.5\times10^{-44}\ \nu \times L_\nu$, with SFR in units of M_{sol}/yr, ν in Hz, and L_ν in erg/s/Hz. The reddening coefficient for the NUV band to correct the foreground dust extinction of our Milky Way is $R_{NUV} = A_{NUV}/E(B–V) = 7.8$.

(i) Calculate the surface area of a sphere with a radius of 1 parsec in units of log (A/cm^2).

(ii) Derive an equation for log L_ν in units of erg/s/Hz as a function of NUV AB magnitude, recession velocity and E(B–V). Simplify the equation for the distance to the Coma Cluster.

(iii) Derive an equation for SFR in units of M_{sol}/yr as a function of log L_ν in units of erg/s/Hz.

(iv) Using the table twomrs_Xm.csv from the 2MASS Redshift Survey, select two samples of galaxies: one with likely members of the Coma Cluster, and one of a thin shell surrounding the Milky Way at a distance of 100 Mpc. Estimate stellar masses and star-formation rates for each galaxy and present the equations you use for that.

(v) Present a CMD (colour-magnitude diagram) and an SFMD (star formation-mass diagram) and describe the features in these including differences between field and cluster galaxies.

(vi) Determine to what mass the SFMD is complete and support your statement with a relevant diagram or calculation.

(vii) Discuss briefly, how the Milky Way (SFR = ~2 M_{sol}/yr, M^*/M_{sol} = ~9×10^{10}) and Andromeda Galaxy (SFR = ~0.35 M_{sol}/yr, M^*/M_{sol} = ~15×10^{10}) compare to the galaxies in the SFMD.

Q3: A new experiment to probe cosmic expansion. (20%)

At a conference you listen to an in-depth presentation that convincingly argues that type-Ia supernovae should not be considered standard candles; the reason: their progenitors evolve with cosmic epoch due to chemical composition changes, so that their average absolute peak magnitude drifts with redshift. Thus, the presenter argues, we should not believe any distance measurements from supernovae; Cepheids, in contrast, should be considered reliable as we do not even see them to distances where gradual cosmic evolution could possibly be relevant. The downside of Cepheids is that we can measure them reliably only to a distance of 20 Mpc.

While you think deeply about this troublesome finding, you recall that one of your favourite collaborators has access to an instrument with which you can measure very well the rotation curves of galaxies with a spatial resolution of 1 arcsecond.

Design an experiment involving your collaborator, with which you can measure distances to galaxies while avoiding type-Ia supernovae. Write a message to your collaborator describing (i) how your proposed experiment is supposed to work, (ii) out to what distance you think it might work, and (iii) whether it might suffer from any effects of cosmic evolution or not; make sure you explain your assumptions to support your derivations.

Q4: Scrutinizing a photometric-redshift experiment. (20%)

You are an advisor for a research committee, reviewing a proposal for a research project.

The proposal aims at an in-depth study of cosmic large-scale structure by observing 10,000 deg^2 of sky area with multi-band imaging. The 3D picture of the Universe will be derived using a new method for estimating photometric redshifts: the method is precise and bias-free, in that it assigns to any observed galaxy a measured redshift that differs from the true redshift by symmetric Gaussian noise with an RMS uncertainty of $\sigma_z \sim 0.02$. From the known redshift, the luminosity of the galaxy can be estimated, and the analysis will use galaxies with at least 10 billion solar luminosities, for which the survey is designed to be complete out to z~0.15.

The proposal claims that, using the novel photo-z method, it will determine the relative number of galaxies in the redshift bins of z=[0;0.02], z=[0.02;0.4], z=[0.04;0.06], z=[0.06;0.08], z=[0.08;0.1] free of bias. Explain why you believe or don't believe that the proposal can deliver on this promise.

Submit your answers as a PDF file. Scanned handwriting is acceptable but please convert any non-PDF documents into PDF before uploading.